

Possible co-existence of superconductivity and magnetism in heavy fermion systems

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Abstract . The Periodic Anderson Model with an exchange induced non phononic pairing interaction is considered to study the possible co-existence of superconductivity and magnetism in a heavy fermion system. Various two-site states with spin are used as basis. Entropy is calculated and it is found to be lowered giving a signature of possible ordering. It is found that there is a critical hopping below which ordering starts and the ordering temperature has a dependance on the exchange parameter J , d - d and f - f pair densities and intersite spin correlations are obtained and their variations with the correlation U and the exchange parameter J are studied. Co-existence of two phases are observed within a certain range of values of J . It is found that the nature of co-existence is sensitive to the strength of hybridization and is fairly independent of the strength of correlation. Results are compared with the current status of the concept.

Keywords Heavy fermion, superconductivity, magnetism

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1. Introduction

The complex and unusual properties of heavy fermion systems have attracted considerable interest [1, 2] during the last two decades. Since the mid-seventies several hundred heavy-fermion compounds have been discovered and a few of them have been found to show superconductivity. These materials are characterised by a dense lattice of magnetic rare earth or actinide ions immersed in a conducting host. They bypass the normal development of ordered antiferromagnetism (AF) to form a new kind of electron fluid and the resulting metallic state contains quasiparticles with effective masses upto a thousand times greater than a bare electron. Thus in CeCu_6 the presence of only 14% Cerium in the Copper host increases the effective mass of the electrons by a factor of 1600 [3]. The heavy electron compound Ce_xCuSi_2 is near the phase boundary between SC and AF and shows an extreme sensitivity to Ce concentration. On reducing x , the ground state is transformed from the spin singlet SC to AF. For $x = 0.99$, several experiments indicate the co-existence of SC and the so called AF phase. In CePd_2Ga_3 , ferromagnetic ordering breaks down as function of external pressure [5]. Historically such co-existence was first reported by Matthias in Chevrel phases of some [4] ternary compounds in which the interaction between magnetic and superconducting

electrons are weak. Such co-existence is also observed in organic and cuprate high T_c superconductors. But unlike the Chevrel phase superconductors, heavy fermion superconductivity (HFS) owes its both ordering effects to the same $4f$ or $5f$ electrons characterised by strong correlation.

Most attempts to understand HF theoretically are based on the Anderson model [6]. This model describes a system of uncorrelated conduction electrons which hybridizes with either a single localised f -electron (Single Impurity Anderson model SIAM) or lattice of many localised f -electrons (Periodic Anderson model PAM). However the mechanism behind the superconducting behaviour of heavy electron fluid has not yet been understood comprehensively. It is still debatable whether the pairing is singlet or triplet like [7, 8]. A phonon mediated pairing mechanism was proposed by Zielinski [9] who also highlighted the different roles played by d - d , d - f and f - f interactions. A d - f exchange induced non-phononic pairing mechanism has also been successfully used [10, 11]. Off late, a composite pairing mechanism in which f -electron local moment is partly quenched with subsequent condensation of superconducting pair is proposed [12].

In this work, a Hamiltonian of the heavy fermion system is visualised through Periodic Anderson model with suitably chosen exchange induced pairing interaction. Quantities such

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